Comparison of Processing Strategy for Time and Frequency Transfer Using GNSS

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Abstract We have tested GNSS data processing for time and frequency (T&F) transfer prior to performing international VLBI T&F transfer experiments between two lattice clocks operated by INRIM (Italy) and NICT (Japan). Modified Allan deviation values show that precise point positioning (PPP) with ambiguity resolution (PPP-AR) and PPP by a Japan Aerospace Exploration Agency (JAXA) GNSS processing tool, MALIB, perform similarly with best-case one-day instabilities on the order of 10^{-15} for the Koganei–Medicina baseline. Although further investigation is required to evaluate the PPP-AR technique, preliminary results imply that this technique is sufficient for validating the international VLBI experiments between INAF and NICT for the comparison of two lattice clocks.

Keywords Time and frequency transfer, GNSS, PPP, IPPP, PPP-AR

1 Introduction

The National Institute of Information and Communications Technology (NICT) is planning to perform international frequency-transfer experiments using compact VLBI systems equipped with a broadband receiver during FY2018. The 34-m Kashima and 2.4-m Koganei antennas of NICT and another 2.4-m antenna system will be used in the experiments. We have already installed the latter antenna system at the Medicina Radio Astronomy Station of Italy in August 2018, near the 32-m antenna. The primary aim of the experiments is to perform a direct remote comparison of two optical lattice clocks, an *Yb* clock operated at the Istituto Nazionale di Ricerca Metrologica (INRIM), Turin, and a *Sr* clock of NICT, Koganei, as shown in Figure 1.

We will perform precise frequency transfer measurements using GNSS on the NICT-INAF baseline in order to validate and evaluate the VLBI experiments. We describe preliminary results in this short paper.

2 GNSS Time and Frequency Transfer

The time-transfer accuracy of VLBI experiments will be verified by comparison with that of an independent technique using the GNSS. Time and frequency (T&F) transfer using the GNSS code and carrier phase observations are popular techniques for precise clock comparisons. In particular, GNSS data processing based on precise point positioning (PPP), which is the standard technique for geodetic applications, allows highly precise T&F comparisons between remote clocks. PPP least-squares solutions showed improved stability relative to traditional GPS time synchronization methods such as the common-view GPS, reaching a stability of a few parts in 10^{-15} for an averaging time of one day [2].

3 Analysis

The conventional PPP processing strategy has treated the phase ambiguities of GNSS signals as float val-

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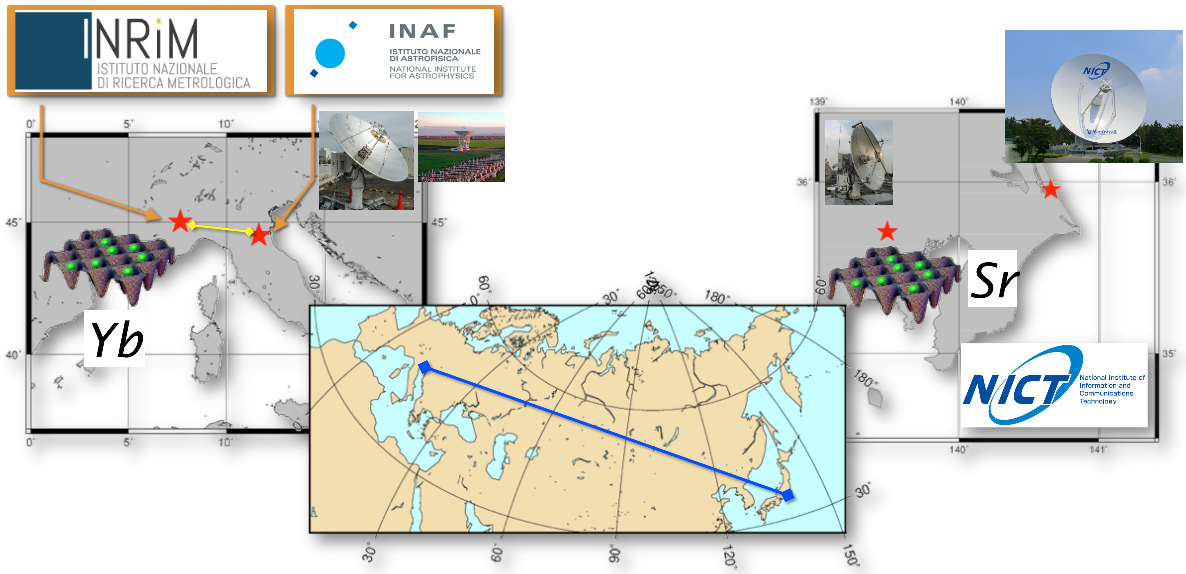

Fig. 1 Planned international VLBI experiments to link two optical lattice clocks on the INAF–NICT baseline. The *Yb* lattice clock at INRIM is linked to the clock at INAF via an optical fiber link.

ues. However, we have to take into account the integer-cycle nature of the phase ambiguities in order to overcome the current limitations of GPS for clock comparisons [3]. In recent years, new GNSS PPP processing tools that implement an integer carrier phase ambiguity resolution (AR) have been developed and used in practical applications. This technique is called PPP-AR or IPPP (PPP with integer ambiguity resolution). We have carried out time-transfer comparisons using GNSS in order to evaluate the performance of PPP-AR before the international VLBI T&F experiments involving Medicina and Koganei.

Table 1 Processing setting.

(legend in Figures 2–4)	Software	Orbit	Ambiguity Resolution
PPP-Wizard/AR	PPP-Wizard	GRG	Yes
PPP-Wizard/PPP (GRG)	PPP-Wizard	GRG	No
PPP-Wizard/PPP (IGS)	PPP-Wizard	IGS	No
MALIB/PPP-AR	MALIB	JXF	Yes
MALIB/PPP	MALIB	JXF	No

The GNSS data sets obtained from April 8 to May 10, 2017 were processed using two PPP-AR processing tools, namely, MALIB (MADOCA PPP Library) developed by the Japan Aerospace Exploration Agency (JAXA) and PPP-Wizard (PPP with integer and zero-difference ambiguity resolution demonstrator) developed by the Centre National d'Études Spatiales (CNES). We have used IGS and GRG products (precise orbit, satellite clock, and earth rotation parameters) for PPP-Wizard processing. In MALIB processing, we have used MADOCA products (precise orbit, satellite clock, and fractional cycle bias (FCB) data).

4 Results

Figure 2 depicts clock differences from each GPS analysis of the Koganei (NICT)–Medicina (INAF) baseline. Similar variations for both MALIB results (PPP-AR and PPP) are observed. The amplitude and phase of two variations are almost identical. On the other hand, all PPP-Wizard results show unknown diurnal signatures and offsets. The cause of these signatures is under investigation at present.

Modified Allan deviation (MDEV) values were derived for each GPS data processing in order to estimate the frequency link stability. Figure 3 depicts the results for the Koganei (NICT)–Medicina (INAF) baseline, while Figure 4 depicts the results for Koganei (NICT)–KRIS (KRISS: Korea Research Institute of Standards and Science). Fujieda et al. already demon-

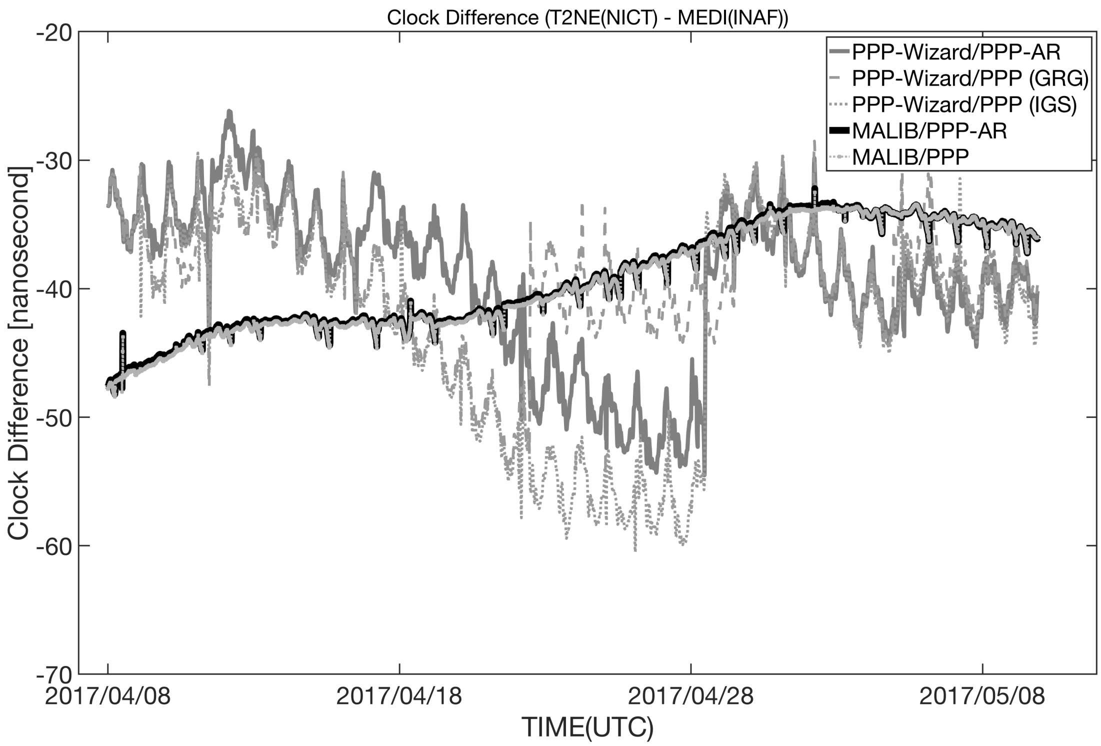

Fig. 2 Difference between UTC(NICT) and INAF clocks (MEDI).

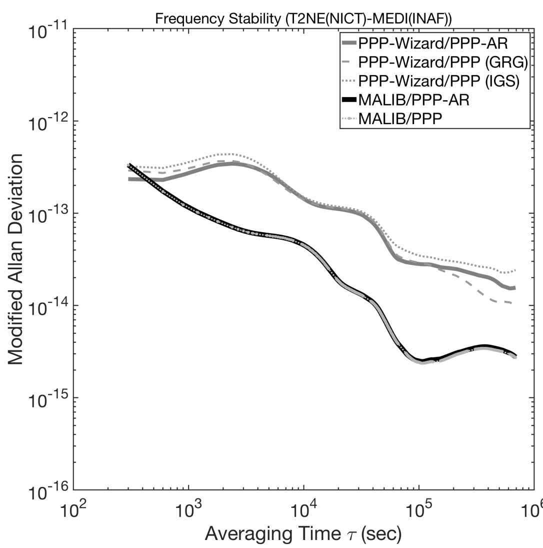

Fig. 3 Modified Allan deviation (MDEV) plot for frequency link over NICT–INAF (MEDI) using GNSS.

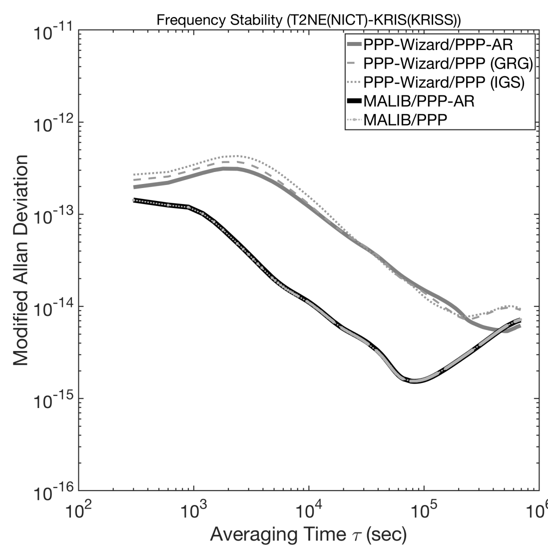

Fig. 4 A MDEV plot for frequency link over NICT–KRISS using GNSS.

strated that two-way carrier-phase satellite frequency transfer (TWCP) and IPPP have superior long-term stability between NICT and KRISS [4].

Both results show that PPP-AR and PPP by MALIB perform similarly with best case one day instabilities on the order of 10^{-15}. On the other hand, MDEV values obtained by PPP-Wizard processing were much worse and one day instabilities were on the order of less than 10^{-14}.

5 Conclusions

We have tested GNSS data processing for time and frequency (T&F) transfer prior to performing international VLBI T&F transfer experiments between two lattice clocks operated by INRIM (Italy) and NICT (Japan). Modified Allan deviation values obtained by the MALIB GNSS processing tool of JAXA show that both PPP-AR and PPP processing perform similarly with best case one day instabilities on the order of 10^{-15} for the Koganei–Medicina baseline. Preliminary results imply that this technique is sufficient for validating the international VLBI experiments between INAF and NICT for the comparison of two lattice clocks at NICT and INRIM. Although a superior stability by IPPP is not shown in our results, further investigation is required to evaluate PPP-AR.

6 Outlook

We will process the data sets using both the CSRS-PPP tool developed by Natural Resources Canada and the C5++ tool developed by NICT, Hitotsubashi University, and JAXA [1]. In addition, the international VLBI experiments between INAF and NICT have already started in early October 2018. The comparison results between two lattice clocks on the intercontinental baseline using GNSS and VLBI will be reported in the next fiscal year.

Acknowledgements

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